# Sleep Duration in Rough Sea Conditions

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**INTRODUCTION:** Environmental motion can affect shipboard sleep of crewmembers. Slamming and similar harsh motion may interfere with sleep, whereas mild motion and sopite syndrome may enhance sleep. If sleep needs vary by sea condition, this factor should be considered when assessing human performance at sea. The goal of this study was to assess sleep duration in different sea conditions.

**METHODS:** Crewmembers ($N = 52$) from a U.S. Navy vessel participated in the study while performing their normal daily schedule of duties. Sleep was assessed with wrist-worn actigraphy. Motion sickness and sopite syndrome were assessed using standardized questionnaires.

**RESULTS:** In rough sea conditions, crewmembers experienced increased severity of motion sickness and sopite syndrome compared to their ratings during calmer sea conditions. Crewmembers slept significantly longer during sea state 5-6 compared to sleep on days with sea state 4 (25% increase) and sea state 3-4 (30% increase). Specifically, daily sleep increased from $6.97 \pm 1.24$ h in sea state 3-4, to $7.23 \pm 1.65$ h in sea state 4, to $9.04 \pm 2.90$ h in sea state 5–6.

**DISCUSSION:** Although the duration of sleep in rough seas increased significantly compared to calmer sea conditions, causal factors are inconclusive. Accumulated sleep debt, motion-induced fatigue, and sopite syndrome all may have contributed, but results suggest that motion sickness and sopite syndrome were the predominant stressors. If sleep needs increase in severe motion environments, this factor should be taken into account when developing daily activity schedules or when modeling manning requirements on modern ships.

**KEYWORDS:** sleep, sopite syndrome, motion sickness.

Matsangas P, Shattuck NL, McCauley ME. *Sleep duration in rough sea conditions.* Aerosp Med Hum Perform. 2015; 86(10):901–906.

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When at sea, ship crews work in a nonstationary environment that is continually moving. These conditions can lead to performance degradation resulting from issues such as motion sickness and disruption of manual material handling. The term "motion sickness" encapsulates a constellation of symptoms ranging from headache to emesis.[14] In environments with real motion, the severity of motion sickness is determined in large part by the characteristics of the motion envelope (i.e., acceleration, amplitude, and frequency).[16] In general, motion sickness severity increases with acceleration magnitude in the frequency range between 0.1 and 1 Hz. Severe symptoms of motion sickness may incapacitate the human, preventing them from working, whereas even mild motion sickness may be accompanied by deteriorations in performance.[12] The term "sopite syndrome" was introduced in the 1970s to systematically address part of these nonincapacitating symptoms.[7] Sopite syndrome is a symptom complex that develops as a result of exposure to real or apparent motion and is characterized by drowsiness, lassitude, lethargy, mild depression, and reduced ability to focus on assigned tasks. Sopite syndrome is most clearly distinguished in healthy individuals who are not suffering from sleep deprivation, or mental or physical fatigue.[11]

In operational environments, motion sickness may occur in conjunction with other stressors, including sleep deprivation.[13] Although there are individual differences in sleep requirements, sleep deprivation results from obtaining less than the required amount of 8 h of sleep each night.[13] It can be challenging to distinguish between the performance degradation caused by sopite syndrome and motion exposure, and similar changes in performance caused by sleep deprivation.

Even though humans are affected by all three stressors (motion sickness, sopite syndrome, and sleep deprivation), few studies have focused on the combined effects of environmental

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This manuscript was received for review in January 2015. It was accepted for publication in July 2015.

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DOI: 10.3357/AMHP.4250.2015

motion, emergent motion sickness, and sleep. Based on subjective reports, it has been shown that vessel motion is correlated with sleep problems, i.e., severe ship motion leads to increased sleep problems compared to calmer motion conditions.[3] These findings are aligned with an earlier work, which assessed the effect of moderate motion on sleep using electroencephalography.[10] These results suggested that moderate motion per se did not affect the sleep patterns of nonmotion sick individuals.

However, symptoms of sopite syndrome (before the introduction of the term, researchers referred to soporific symptoms as part of the motion sickness complex) lead not only to increased sleepiness, but also are associated with more sleep. Experiments in the Slow Rotation Room found that motion-sick subjects slept more than usual.[6] Specifically, only those subjects who felt sick in motion conditions reported feeling fatigued after the motion stimulus ceased to exist and slept more hours than usual during the subsequent night. Reason and Brand[17] reported a study involving a 3-d exposure to angular accelerations. Results showed persistent and overwhelming drowsiness, as well as abnormally long hours of sleep, with many subjects falling into deep sleep lasting several hours. It is notable that motion sickness has also been associated with elevated melatonin secretion,[8] a hormone known to modulate sleep/wake cycles and circadian drowsiness.[2] Mild vestibular stimulation also is known to promote sleep onset. Physical rocking is widely used to induce infant sleep and to soothe babies.[20]

This review suggests that, depending on its severity and characteristics, environmental motion may affect sleep, but this association is confounded by the development of sopite syndrome. Although vigorous motion may interfere with sleep, mild motion and sopite syndrome may actually facilitate and enhance sleep. In our literature review, we failed to identify any operational studies assessing how crewmembers' sleep changes as a result of sea conditions. If sleep needs vary by sea condition, this factor should be considered when assessing human performance at sea. The goal of this study was to assess crew sleep in different sea conditions.

## METHODS

### Subjects

Overall, 54 individuals (52 active-duty U.S. Navy members and 2 civilians, 31.6 ± 5.46 yr in age) volunteered to participate in the study, 39 in the first data collection period and 43 in the second. There were 28 crewmembers who volunteered for both data collection periods. Approximately 90% of the subjects in the first period and 85% in the second period stood watch on one of various schedules used on the ship (i.e., 12/12, 4/8, 5/10, 3/6, 6/12, or 8/16 watch-standing schedules). Approximately 50% of the subjects in the first period and 62% in the second stood watch in a rotating schedule leading to different sleep times every day.[18,19] For approximately 75% of the crewmembers participating in both data collections, their watch rotations changed between the first and the second period. However, these changes did not have a specific pattern. The study protocol was approved in advance by the Institutional Review Board of the Navy Experimental Diving Unit. Each subject provided written informed consent before participating.

### Equipment

Sleep was assessed with actigraphy, a validated method used extensively in clinical and field studies to assess sleep patterns.[1] Actiwatches are wrist-worn devices which include a solid-state piezoelectric accelerometer to collect human activity information. The actiwatch we used was the Philips Respironics Spectrum (acceleration range 0.5 to 2 g peak value; frequency bandwidth 0.35 to 7.5 Hz; 0.025 g sensitivity; 23 Hz sampling rate). Data were scored using Actiware software version 6.0.0 (Phillips Respironics, Bend, OR). With 1-min epochs, the medium sensitivity threshold (40 counts per epoch) was used with 10 immobile minutes being the criterion for sleep onset and sleep end (all values are default for this software). All subjects completed a daily activity log throughout the study, documenting their daily routine. The logs covered a 24-h period in 30-min intervals.

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Two standardized questionnaires were used to assess motion sickness severity, the North Atlantic Treaty Organization (NATO) Performance Assessment Questionnaire (PAQ)[3] and the Motion Sickness Assessment Questionnaire (MSAQ).[5] The MSAQ includes four subscales (gastrointestinal, central, peripheral, and sopite-related). The sum of the subscale scores is the overall motion sickness score. Although the PAQ was used in both data collection periods, the MSAQ was used only in the second period.

During both data collection periods, the ship executed planned sea trials throughout the day. During the periods of sea trials, sea state data were obtained with the Tsurumi Seiki Co. wave measuring system. In order to further assess whether these motion data were representative of sea state, we also used historical data derived from the National Oceanic and Atmospheric Administration National Climatic Data Center. For the first data collection period, sea state data were used from Station 46,086 (LLNR 81)–San Clemente Basin, located 27 nmi southeast of San Clemente Island, CA, and from Station 46,219, located in the vicinity of San Nicolas Island, CA. For the second data collection period, sea state data were used from Station 46,022 (LLNR 500)–Eel River, located 17 nm west-southwest of Eureka, CA.

### Procedure

The quasi-experimental study was conducted on a 3000-ton/400 ft U.S. Navy vessel over two data collection periods. For the first period, 3 to 12 May 2013, the ship traveled in the area of San Diego. For the second period, between January 23 and February 3, 2014, the ship was in the area west of northern California and Oregon. Subjects continued their normal daily schedule of duties during the study and were instructed to complete the test questionnaire twice per day.

Based on the sea state data, it was concluded that in the first data collection period, sea state ranged between high 3 to low 4 ("Condition 1"). The second data collection period was characterized by rougher sea states as compared to the first period.

Within the second period, we identified two groups of days which we used for the sleep analysis. Our decision was made based on the availability of sleep data and the sea state conditions. Specifically, sea condition on May 25 and 26 was classified as sea state 4 ("Condition 2"), whereas 28 and 29 May were classified as sea state 5-6 ("Condition 3"). Our analysis is focused on the comparison of Condition 3 with Conditions 1 and 2. Although overlapping to some degree, Condition 2 was rougher than Condition 1.

## RESULTS

### Motion Sickness and Sopite Syndrome Severity

Unfortunately, the attrition rate over the course of both data collection periods was extremely high. The response rate of the test questionnaires in the first data collection period was 35% and even lower (23%) in the second period, which was characterized by rougher sea conditions. Furthermore, responses were unequally distributed within the data collection periods and crewmembers who were motion sick tended to withdraw at higher rates from participation in the study. Hence, the data were inconsistent and not appropriate for analyzing with a traditional statistical approach. However, a descriptive approach provides interesting insights into the occurrence and severity of motion sickness symptoms.

In the NATO PAQ, subjects were asked to rate on a 4-point Likert scale (0 = not at all, 3 = extreme) the severity of 10 symptoms: mental fatigue, physical fatigue, sleepiness, headache, apathy ("just don't care"), tension/ anxiety, vomiting or retching, nausea ("not vomiting … yet"), stomach awareness, or other symptoms. In the first data collection period (Condition 1), the most frequently observed symptom was sleepiness (77.8% of the responses, 91% of the subjects), followed by mental fatigue (68.2% of the responses, 97% of the subjects), physical fatigue (66.3% of the responses, 91% of the subjects), apathy (29.3% of the responses, 30% of the subjects), and tension/anxiety (25.2% of the responses, 59% of the subjects). In the second data collection period (Conditions 2 and 3) the frequency pattern of symptoms is the same, but with reduced prevalence, probably because of the increased attrition. In contrast to Condition 1, though, crewmembers in Conditions 2/3 reported more gastrointestinal symptoms. Vomiting or retching in Conditions 2/3 was reported in three responses (7.5% of the subjects) compared to one response in Condition 1. Nausea in Conditions 2/3 was reported in nine responses (20% of the subjects) compared to one response in Condition 1. Stomach awareness in Conditions 2/3 was reported in 17 responses (25% of the subjects) compared to 10 responses (19% of the subjects) in Condition 1 (3.7%). Furthermore, headache was reported by 50% of the subjects in Condition 1 compared to 55% in Conditions 2/3.

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The severity of seasickness was further evaluated in the PAQ by an 11-point Likert scale (0 = feel fine, 10 = feel awful). In Conditions 2/3, 27.5% of the subjects reported seasickness (15% of the questionnaires with a severity ranging up to "7") compared to 21.9% of the subjects (10.7% of the questionnaires with a severity ranging up to "3") in Condition 1. In Conditions 2/3, 57.5% of the subjects reported taking seasickness medication (48.1% of the questionnaires) compared to 18.8% of the subjects (6.64% of the questionnaires) in Condition 1. Notably, in the first data collection period the attrition rate did not change with the use of seasickness medication. However, attrition rate differed in the second period that was characterized by more severe sea state conditions. Specifically, subjects taking seasickness medication had an approximately twofold higher response rate compared to subjects who did not use medication, 30% versus 14%, respectively.

Lastly, the maximum MSAQ Total score in Condition 3 (sea state 5-6) was 63.9/100 compared to 28.5/100 in Condition 2 (sea state 4). **Table I** shows the severity of motion sickness and sopite syndrome symptoms in the three Conditions. Overall, the trend apparent in these results suggests that in Condition 3 (sea state 5-6), crewmembers suffered from motion sickness and sopite syndrome symptoms considerably more than in Conditions 1 and 2 (sea states up to 4). This conclusion is further emphasized

**Table I.** Motion Sickness and Sopite Syndrome Severity.

| SURVEY | SYMPTOM | MOTION CONDITION<br>CONDITION 1<br>SEA STATE 3 – LOW 4 | CONDITION 2<br>SEA STATE 4 | CONDITION 3<br>SEA STATE 5-6 |
|---|---|---|---|---|
| MSAQ | Felt sick to stomach* | | 2 | 3 |
| | Felt faint-like* | | 3 | 5 |
| | Felt sweaty* | | 5 | 8 |
| | Felt drowsy* | | 4 | 6 |
| | Felt cold/sweat* | | 2 | 4 |
| | Felt disoriented* | | 3 | 7 |
| | Felt nauseated* | | 1 | 8 |
| | Felt as if I may vomit* | | 1 | 6 |
| | Felt uneasy* | | 2 | 8 |
| | Total score** | | 28.5 | 63.9 |
| | Gastrointestinal score** | | 13.9 | 69.4 |
| | Central score** | | 31.1 | 64.4 |
| | Peripheral score** | | 44.4 | 70.4 |
| | Soporific score** | | 41.7 | 52.8 |
| NATO PAQ | Experienced vomiting or retching† | 1 | 0 | 3 |
| | Experienced seasickness‡ | 3 | 2 | 7 |
| | Motion sickness interfered with my duties | 1 | 1 | 4 |

Numbers refer to maximum response in the corresponding condition.
* For all MSAQ symptoms: Not at all = 1, Severely = 9.
** For all MSAQ scales: Minimum = 11.1, Maximum = 100.
† Not at all = 0, Extreme = 3.
‡ Felt fine = 0, Felt awful = 10.

by the fact that crewmembers were experienced sailors with 5.83 ± 3.0 yr of sea time and can, therefore, be considered as adapted to normal sea conditions.

### Sleep

Because of missing actigraphic data, only 25 subjects were included in the sleep analysis in the first data collection period and 19 subjects in the second period. Each subject provided on average 5.9 ± 1.5 d of sleep data in the first phase (250 sleep episodes in total) and 8.52 ± 1.76 d of sleep data in the second phase. The average rest episode was 4.30 ± 3.04 h, whereas the average sleep episode was 3.76 ± 2.77 h. On average, subjects received 7.87 ± 1.72 h of daily sleep. Daily rest amount (time in bed) was on average 11.6% ± 3.15% more than the corresponding sleep amount.

Next, we investigated the association between daily sleep amount and sea state. A nonparametric pairwise comparison, based on a 1-sided Wilcoxon Signed Rank test, showed that subjects slept significantly more in the days in sea state 5-6 compared to the days in sea state 4 (25% increase, S = 41.0, $P$ = 0.016) and sea state 3-4 (30% increase, S = 13.5, $P$ = 0.065). Specifically, daily sleep increased from 6.97 ± 1.24 h in sea state 3-4, to 7.23 ± 1.65 h in sea state 4, and 9.04 ± 2.90 h in sea state 5-6. These results are shown in **Fig. 1**. Vertical bars denote 1 SD. It should also be noted that 75% of the participants in the second data collection period slept more in Condition 3 (sea state 5-6) as compared to Condition 2 (sea state 4).

## DISCUSSION

Results show that in sea states up to 4, daily sleep duration ranged between 7 and 7.23 h on average. Although this daily sleep duration is less than the scientifically recommended amount (8 h for a healthy adult), it is comparable to earlier sleep studies with actigraphy conducted on U.S. Navy ships.[13] However, our results also show that daily sleep duration increased to 9 h in sea state 5-6, approximately a 2-h (25%) increase compared to sleep in sea states up to 4. Interestingly, these results are the first time we have observed such a long duration of daily sleep in the 14 yr of operational sleep research with actigraphy at the Naval Postgraduate School.[13] Our literature review also failed to identify any studies at sea with such a large increase in daily sleep duration.

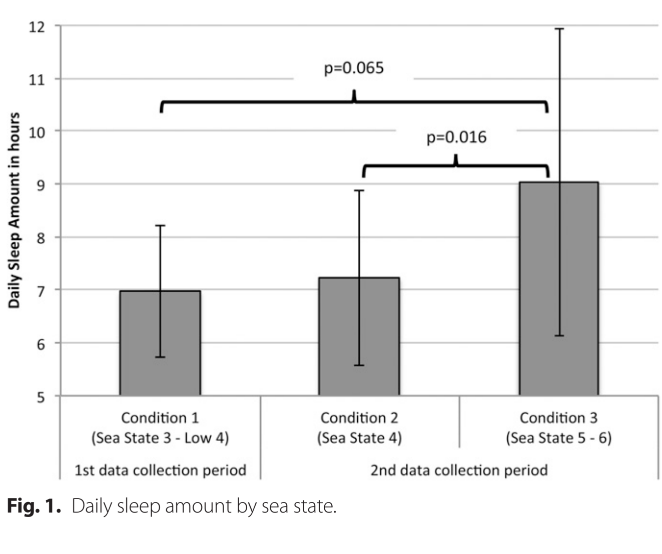


**Fig. 1.** Daily sleep amount by sea state.

The data reported here are not sufficient to determine why there was such a substantial increase in sleep duration at sea state 5-6. However, we have identified three plausible explanations that can be considered. For each explanation we will provide the rationale of how well it may explain our results. First, sleep deprivation accumulates to a greater sleep debt toward the end of the data collection period. The rougher sea state days (days 28 and 29) occurred close to the end of the second data collection period, whereas the calmer days occurred close to the beginning of the data collection. Hence, subjects had accumulated a large sleep debt by the time the days with rough seas began. Although plausible, our literature review failed to identify such a sleep difference between the beginning and the end of the underway period, especially given the short 10-d duration of the underway period. Furthermore, we have never observed such a pattern in our previous sleep studies on U.S. Navy ships.[13] The fact that the 2-h difference existed even when comparing sleep between days with sea state 5-6 and the first data collection with a lower sea state further supports that sleep debt is not a plausible explanation in our study.

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Second, the results could be due to motion-induced fatigue (MIF) stemming from the severe environmental motion. The concept of MIF is based on the fact that performing a physical task at sea is more fatiguing than performing the same task in a stationary environment. Although physical tasks are always related to some amount of physiological fatigue (i.e., weariness after exertion), this amount is increased when the whole body is exposed to motion such as that induced in the higher sea states. Although it is a well-recognized problem in the naval environment, MIF at sea has not been thoroughly investigated. Some studies, however, provide interesting insights. A meta-analysis by Youngstedt and colleagues[21] showed that aerobic exercise increases total sleep time, with a median sleep difference of approximately 10 min. However useful, their findings refer to aerobic activity, whereas current research has provided evidence that being in a moving environment can also be anaerobic.[15] Most importantly, though, the small effect identified by Youngstedt and colleagues does not explain the 2-h sleep difference in our study.

We believe that our results are better explained if we consider the effect of increased motion sickness and sopite syndrome severity for the days with rough sea conditions. Since the 1960s, motion sickness research has provided evidence that symptoms of sopite syndrome may lead to long hours of sleep.[6,17] To our knowledge, this evidence has not been verified in operational studies. Hence, this effort is the first field study at sea supporting the finding that sopite syndrome leads not only to increased drowsiness and degraded performance,[12] but also increases the need to sleep. Although the ability to provide analytical comparisons from our data is affected by the attrition in motion sickness responses, the trend observed is that crewmembers in sea state 5-6 experienced motion sickness and sopite syndrome symptoms considerably more than those in sea states up to 4. Even the twofold difference in response rates, which were higher in calmer seas, supports our argument about the deleterious effect of motion sickness and soporific symptoms at sea.

As part of the discussion for the effect of motion sickness we should also note the potentially confounding effect of seasickness medications used by approximately 60% of the participants in the second data collection period. It is known that central nervous system depressants such as promethazine and scopolamine provide protective benefit against motion sickness, but induce drowsiness.[9] From an operational perspective, we consider the use of such drugs an indirect effect of motion sickness that should be taken into account when addressing the operational impact of motion sickness.

Furthermore, we believe that our results cannot be attributed to a specific watch rotation or day/night reversal because of night shifts for two reasons. First, our subjects were working in various watch schedules, some of which are rotating and are known to lead to different sleep times every day (5/10, 5/15, 6/12).[18,19] In our sample, approximately 50% of the subjects in the first period and 62% in the second stood watch on rotating schedules. Second, during the second data collection, which was characterized by sea state 4 and sea state 5-6 conditions, subjects did not have their schedules changed. Therefore, our within-subject comparison results (showing a 25% increase in sleep duration) are not confounded by changes in watch schedule. It should also be noted that 75% of the participants in the second data collection period showed increased sleep duration in sea state 5-6 compared to sea state 4. With the exception of three crewmembers who did not stand watch, the rest were predominantly watch standers on rotating schedules (5/10, 5/15, 6/12).

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Our results also may be relevant to ship manning decisions. If the physiological need for sleep increases in severe motion environments, this factor should be taken into account when developing daily activity schedules or when modeling manning requirements on ships. One paradigm for manning is the Navy Standard Work Week (NSWW) model.[4] The NSWW represents a standardized version of 1 wk of work performed by a single enlisted sailor while at sea; it is used to calculate required manning levels. Although not restrictive for commanding officers, the U.S. Navy's guideline notes that extending working hours on a routine basis could adversely affect such matters as moral, retention, safety, etc., and as a policy, such extensions should be avoided. Useful as it may be, this model allocates an 8-h period each day for sleep. Future revisions and improvements of the NSWW model should consider the findings reported here.

This study has a number of limitations. First, there was considerable attrition in the number of subjects, resulting in a reduced survey response rate, especially in rough motion conditions. Operational studies often suffer from high attrition rates. Future efforts must include a larger number of participating crewmembers, and researchers should consider ways to incentivize and motivate subjects to comply with the study protocol (respond to questionnaires, take tests, etc.) and persevere throughout the data collection period. Given the operational aspect of the study, the motion conditions could not be counterbalanced.

Lastly, an issue of concern is the extent to which the ship's motion may have interfered with the human activity detected by the actiwatches. Given that actiwatches are omnidirectional accelerometers used in a moving environment, it is expected that the level of detected activity can be partially attributed to ship motion. Unfortunately, an analytical procedure to distinguish between human-generated and ship-generated motion as detected by an actiwatch does not exist. However, it is also expected that the more severe the ship motion, the more it will affect the activity detected by the actiwatches. Hence, the actigraphic algorithm could potentially calculate less actual sleep in rough sea conditions. Therefore, our findings that sleep duration increases in rough sea conditions may be even larger than indicated in the results reported in this study.

In conclusion, our results show that the duration of sleep in rough seas increased substantially compared to calm sea conditions. Conclusive results as to the causal factor leading to the observed phenomenon cannot be provided, but three plausible explanations are discussed. Accumulated sleep debt, motion induced fatigue, and sopite syndrome may all have contributed, but results suggest that motion sickness and sopite syndrome were the predominant stressors. If sleep needs increase in severe motion environments, this factor should be taken into account when developing daily activity schedules or modeling shipboard manning requirements.

## ACKNOWLEDGMENTS

The authors wish to thank the Human Systems Integration Team at the Naval Surface Warfare Center-Panama City Division (NSWC-PCD), for the collection of sea state data.

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